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MANAGING SOIL CARBON SEQUESTRATION

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Introduction

The premise of soil carbon (C) sequestration is to help reduce carbon dioxide concentration in the atmosphere due to human activities by capturing and diverting CO₂ to secure storage by various means. The material presented here is excerpted from the interactive courseware developed for the Crop Adviser Institute by Dr. Mahdi Al-Kaisi of Iowa State University.

Importance of soil carbon sequestration

The scientific consensus is that levels of greenhouse gases in the atmosphere are increasing, and these increases may reach a level that may trigger serious climate changes in air temperature and violent weather cycles.

Greenhouse gases occur naturally, but changes in their concentrations in the atmosphere impacted by human activities. Naturally occurring greenhouse gases include water vapor, carbon dioxide, methane, nitrous oxide, and ozone. However, anthropogenic activities also add to the levels of many of these naturally occurring gases. Other greenhouse gases do not occur naturally and are generated solely by human activity.

Carbon sequestration by agricultural land has generated international interest because of its potential impacts on and benefits for agriculture and climate change. Agriculture can be one of many potential solutions to the problem of greenhouse gases emissions through implementation of proper soil and residue management techniques. Additionally, agricultural conservation practices such as the use of different cropping and plant residue management, as well as organic management farming, can enhance soil carbon storage. Producers, in addition to the environment, receive benefits from carbon sequestration.

Agricultural ecosystems represent an estimated 11% of the earth's land surface and include some of the most productive and carbon-rich soils resulting in a significant role in the storage and release of C within the terrestrial carbon cycle. Major considerations of the soil C balance and the emission of greenhouse gases from the soil are: (1) the potential increase of CO₂ emissions from the soil contributing to the increase of the greenhouse effect, (2) the potential increase in other gas emissions (N₂) & CH₄) from soil as a consequence of land management practices and fertilizer use, and (3) the potential for increasing C (as CO₂) storage into soils, which has been estimated at 1.4 – 2.6 gigatons of carbon per year (Tans et al., 1990), and to help reduce future increases of CO₂ to the atmosphere.

Carbon benefits to the soil

Soil carbon, or organic matter in general, is important because it is a factor in soil quality functions (Fenton et al., 1999) including:

- Sustaining biological activity, diversity, and productivity
- Regulating and partitioning water and solute transport
- Filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials, including industrial and municipal byproducts and atmospheric depositions
- Storing and cycling nutrients and other elements within the earth's biosphere

The impact of soil organic matter on these listed soil qualities and functions may be broken into physical, chemical, and biological effects.

Physical effects: soil aggregation, erosion, drainage, aeration, water-holding capacity, bulk density, evaporation, and permeability.

Chemical effects: cation exchange capacity; metal complexing; buffering capacity; supply and availability of N, P, S and micronutrients; and adsorption of pesticides and other chemical inputs.

Biological effects: activities of bacteria, fungi, actinomycetes, earthworms, roots, and other macro- and microorganisms. Different sources of organic matter supply soils with carbon to replenish their C and nutrient pools. However, organic materials added to the soil contain a wide variety of C compounds with varying decomposition rates. Changes in environmental factors can also cause changes in the rate of decomposition of organic materials in soils, such as moisture status, soil aeration, soil temperature, pH, and availability of minerals.

Carbon pools and sinks

Soils store a significant amount of carbon. It has been estimated that global soils contain approximately 1,650 gigatons of carbon (Post et al., 1998). As a component of the carbon cycle (Fig. 1), soils can be either net sources or sinks of atmospheric carbon dioxide.

Changes in land use and agricultural activities during the past 200 years have made soil act as net sources of atmospheric CO₂. Evidence from long-term experiments suggest that carbon losses due to oxidation and erosion can be reversed with soil management practices that minimize soil disturbance and optimize plant yield through fertilization. It is possible that improved land management may result in a significant increase in carbon storage in the soil. Because of the relatively long turnover time of some soil carbon fractions, this could result in storage of a sizable amount of carbon in the soil for periods as long as several decades.

Several processes can affect the storage of carbon in soils. The amount of carbon stored in the soil system depends on the rate and magnitude of the processes, both of which may be influenced by agricultural management systems and practices.

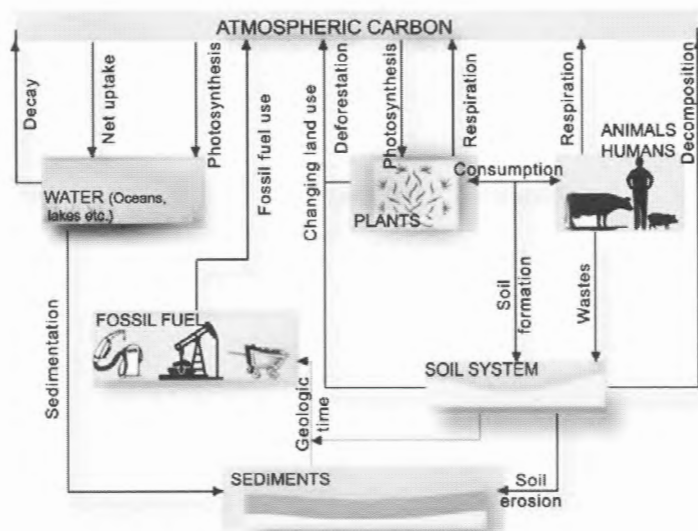


Fig. 1. Carbon cycle sources and sinks.

Processes affecting carbon sequestration in soils

Organic production

Carbon production can be increased through photosynthesis, in which permanent vegetative cover can store a significant amount of carbon dioxide as organic carbon. The volume of vegetation acts as a sink for capturing CO_2 and secures storage of it as carbon. Production practices and land use can greatly affect the carbon status in the soil system. During plant growth, CO_2 from the atmosphere will be fixed in the plant as carbon compounds. Therefore, the primary carbon source is the plant which has initially manufactured the carbon during photosynthesis.

Minimize organic carbon breakdown

The oxidation and breakdown of plant residue will accelerate the loss of carbon as CO_2 . Several factors can accelerate organic carbon breakdown including: soil moisture, soil pH, the oxidation-reduction process, soil temperature, soil chemical and physical properties, nutrient status, and plant residue quantity and quality.

The breakdown of residue through conventional tillage and soil disturbance must be minimal to fully maximize potential carbon storage in the soil. As previously stated, carbon stored in the soil has many benefits, including improving soil physical properties such as water infiltration rate, water-holding capacity, aggregate stability, soil structure, soil aeration, and a host of other physical properties. Additionally, carbon storage can contribute significantly towards improving soil nutrient pools and other chemical properties. Plant residues also help provide a positive environment for improving soil microbial populations, which in turn play a significant role during the decomposition process of organic materials.

Soil erosion

Keeping plant residues intact is a critical component of soil management, not only for nutrient

value, but also to protect soil from erosion. Improper soil and residue management may result in increased erosion by water and wind. Soil erosion is a major factor in soil degradation caused by losses of organic matter, the binding factor in soil. In Iowa, water erosion is a significant soil degradation factor, and can be most effectively minimized through the adoption of conservation tillage practices.

The impact of no-tillage practices on improving soil quality in terms of carbon content in the upper soil profile is evident where permanent vegetation has been established in grassy areas. Tillage can cause significant amounts of carbon (*as CO₂ bursts*) loss immediately after tillage. The exposure of soil organic carbon to aeration during tillage and/or erosion increases CO₂ emissions. In addition, soil erosion can cause carbon loss with soil sediments, and be removed from the soil carbon pool, resulting in declines in soil fertility and aggregate stability.

Impacts of conservation practices and fertilizer use

Conservation tillage practices can minimize the rapid breakdown of plant residues, reduce CO₂ emission, and reduce the production of inorganic dissolved nitrogen (*nitrate and ammonium*) in soil. When conventional tillage is replaced by conservation tillage, both CO₂ emissions from soil and N-uptake by crops are reduced.

Soil organic carbon (SOC) content is enhanced by reductions in CO₂ emission, but the reduction in N-uptake results in reduced residue production and lower organic C storage in soils. Also, it was found that reducing tillage significantly decreases SOC loss from soils with high organic matter content.

The Morrow plots at the University of Illinois were established in 1876 to study the yield effects of crop rotations and fertilization (Table 1). Crop sequences (in a single replication) were: continuous corn, corn-oats rotation, and corn-oats-clover rotation, with and without added lime, manure, and rock phosphate (Stauffer, et al., 1940).

Table 1. Changes in organic carbon content in Morrow plots, 1876-1940, University of Illinois (after Stauffer et al., 1940)

| Rotation | Treatment ^a | % Organic C | % Organic matter | % C change ^b |
|------------------|------------------------|-------------|------------------|-------------------------|
| Corn | None | 1.74 | 2.99 | -45.6 |
| | MLP | 2.09 | 3.59 | -34.7 |
| Corn-Oats | None | 2.14 | 3.68 | -33.1 |
| | MLP | 2.44 | 4.20 | -23.6 |
| Corn-Oats-Clover | None | 2.28 | 3.92 | -28.7 |
| | MLP | 3.35 | 5.76 | +4.0 |
| Sod | None | 3.20 | 5.50 | 0.0 |

^a MLP = Manure-Lime-Phosphorus

^b % C changes based on sod C value

The results show that continuous corn plots with no fertilizer decreased soil organic matter (SOM) content by 45.6% in 55 years as compared with the adjacent sod. Neither the cropping system nor the soil treatment had much effect on soil organic carbon below 9 inches deep in the soil profile.

Van Bavel and Schaller (1950) had similar results when comparing a corn-oats-meadow rotation with a continuous corn system in Iowa (Fig. 2). The continuous corn system showed a higher rate of soil carbon decline, from 3.3% to 2.5% from 1932-48. The corn-oats-meadow rotation declined only slightly, from 3.5% to 3.4% over the same period. Though the plots were located on 9% slope gradients and erosion may have partially contributed to the decline, the uncultivated Marshall soil should have soil organic matter of approximately 4.5-5% (Fenton et al., 1999).

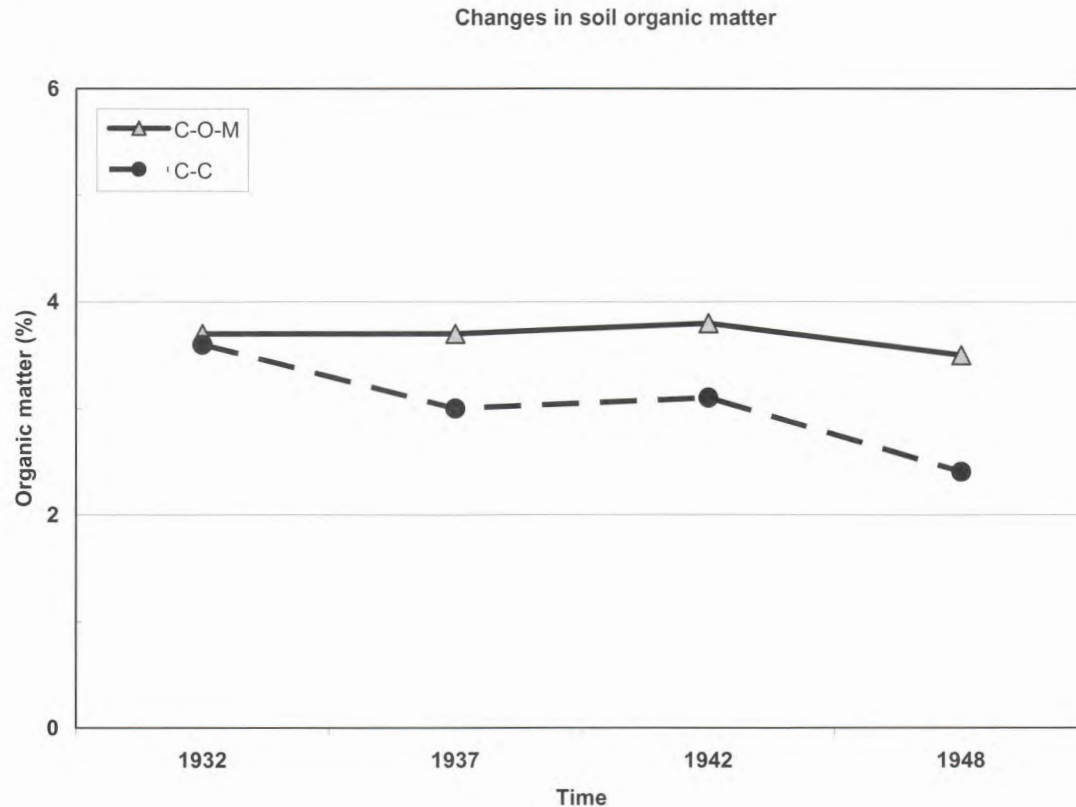


Fig 2. Changes in soil organic matter. (after Van Bavel & Schaller, 1950)

Both of these examples illustrated the benefits of crop rotation systems which leave the soil covered with plant matter and/or residue for the longest periods of time and return the largest percentage of carbon to the soil.

Summary

This material was designed to help explain carbon sequestration and the carbon cycle, present concerns related to elevated atmospheric CO₂ levels, and show how agricultural practices impact the carbon cycle. Carbon sequestration is highly related to tillage, cropping systems, and soil management practices. Research has shown that no-till and permanent vegetation is the most efficient way to store carbon in the soil. Effective manure and nitrogen management, combined with the previous factors contribute significantly to improving soil carbon status.

Producers who reap the benefits of carbon sequestration gain through increased soil productivity,

higher quality soils (improved physical, chemical, and biological properties), and reduced erosion. Carbon credits are another benefit currently being explored by many entities, governmental and private. This issue must be carefully explored and thought must be given to: market value, policies, carbon monitoring procedures, and management entities.

Producers, crop advisers, and others who deal with carbon sequestration must recognize that it is a long-term process, and is reversible. Even short-term management changes, such as a temporary shift to conventional tillage, will alter the long-term soil carbon improvement strategies.

The overall benefits of soil carbon sequestration provide an opportunity to significantly improve soil quality and the environment.

For the entire interactive, computer-based version of this material please visit the Crop Adviser Institute on-line at www.cai.iastate.edu.

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